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WIDEBAND ARRAY ANTENNA USING I-F TIME DELAY STEERING

John B. Payne III
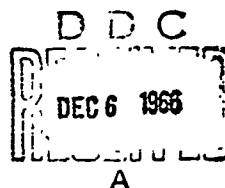
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WIDEBAND ARRAY ANTENNA USING I-F TIME DELAY STEERING

John B. Payne III

FOREWORD

This final technical report was prepared by John B. Payne III of the Advanced
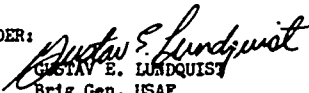tudies Group (EMD) Rome Air Development Center, Griffiss Air Force Base, New
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This report has been reviewed and is approved.

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ABSTRACT

If time delay steering of a wideband array antenna is introduced at the i-f frequency instead of at the r-f level, all of the element signal phases will be different and the summed pulses will not add in-phase to produce a beam in the desired direction. It is found that when i-f delay steering is used, an additional incremental phase shift must be introduced into the local oscillator of each mixer to produce in-phase summation. The delay provides alignment of the envelopes while the local oscillator phase shift provides in-phase summation. This condition is found to be independent of frequency and thus bandwidth. The effect of i-f delay error on the system's response is discussed

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I. INTRODUCTION

In an array antenna that must pass narrowband signals it is well known that the position of the main beam can be steered by varying the relative phase shift between elements. As the bandwidth of signals* processed by phase steered arrays is increased, the output signal-to-noise ratio for off-broadside beam positions deteriorates rapidly [1, 3] and the pulse waveform is distorted affecting the range resolution and accuracy. This deterioration in performance is caused by both the finite propagation time of a short pulse or complex waveform across the array aperture and the change in beam position with respect to the signal spectral components [2]. By replacing the phase shift networks in a parallel feed array with true time delays, the deterioration in performance is eliminated by making the element signal envelopes at the input to the summing network time coincident for all beam positions off broadside.

If the delay steering is introduced at the signal frequency, the antenna is said to be r-f delay steered. When the delay is accomplished at i-f, it is referred to as i-f delay steering. It is also well known that when the element delays are introduced at the signal frequency (r-f delay steering) to align the signal envelopes, in-phase addition of each element signal results. Thus a well-defined beam that is independent of frequency is formed in the desired direction.

Placing the time delay network at the r-f or signal frequency has a number of disadvantages, however. The device must have a bandwidth not only large enough to cover the signal bandwidth, but also large enough to cover the tuning range of the system. Secondly, at higher microwave frequencies, delay devices tend to be either too lossy or dispersive. Lastly, the phase stability for long delays is difficult to maintain.

If the signal delay could be introduced at a lower intermediate frequency (i-f) before signal summation occurs, the majority of the above disadvantages can be eliminated. That is, the delay device must only have a bandwidth equal to the signal bandwidth. The system's r-f center frequency can be moved over the desired range simply by changing the local oscillator frequency and phasing. Secondly, it appears easier to build delay devices at lower frequencies with less loss and dispersion. Thirdly, since a degree of phase shift at r-f is equal to a degree of phase shift at i-f, the required phase stability and allowable error (on a one-to-one basis) of the delay device is easier to obtain at the lower frequencies.

Moving the signal delay from r-f to a lower intermediate frequency before element summation introduces additional problems which have been pointed out by Allen [4]. It is found that with the i-f signal delay lines set to provide time coincidence of the signal envelopes at the input to the summing network, the phase within each element pulse is different and the summed pulses will not add in-phase. Therefore no beam is produced in the desired direction. A beam is produced however, but in another direction. The position of this new beam is highly frequency sensitive and therefore the array will not pass a wideband signal even from that direction without undue distortion.

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* In this document signal bandwidth refers to the spectral width occupied by the signal during one pulse period, i.e., instantaneous bandwidth.

The purpose herein is to show that, with a slight modification to the steering system, an array antenna using i-f delay steering can be made to form a main steerable beam in the desired direction with pointing direction independent of frequency for one setting of the control circuitry. Thus, it is able to accept a wideband signal with negligible degradation or distortion.

II. R-F TIME DELAY STEERING

Figure 1 is a block diagram of an N-element wideband, equally spaced, linear receiving array system (same results apply for the transmit case) using r-f time delay steering. Each element (isotropic) is followed by a wideband, nondispersive and lossless variable delay line, K_n, having an impulse response

$$K_n (t) = \delta_n (t - \tau_n) = 0 \text{ for } t - \tau_T \neq 0$$
$$\int_{-\infty}^{\infty} \delta_n(t - \tau_n)dt = 1 \tag{1}$$

The delay τ_n of each line is set according to

$$\tau_n = (N-n) \ d/c \ \sin \theta_r. \tag{2}$$

With the delay lines set to this value, the envelope of each element signal at the input to the summing network will be time coincident for a signal incident from the θ_r direction. For r-f delay steering, θ_r is the direction of the main beam.

If the signal S(t) is represented by

$$S(t) = p(t) \ e^{j\omega_s t} \tag{3}$$

in which p(t) is the envelope function and ω_s the signal frequency, the array's normalized response to a signal from the θ_s direction is given by

$$G_N = \frac{1}{N}\left\{\sum_{n=0}^{N-1} p\left[t - \frac{Nd}{c} \sin \theta_r - \frac{nd}{c} (\sin \theta_s - \sin \theta_r)\right]\right\}$$

$$e^{j\omega_s \left[t - \frac{Nd}{c} \sin \theta_r - \frac{(N-1)d}{2} \frac{}{c} (\sin \theta_s - \sin \theta_r)\right]}$$

$$\frac{\sin\left[\omega_s \frac{Nd}{2c} (\sin \theta_s - \sin \theta_r)\right]}{N \sin\left[\omega_s \frac{d}{2c} (\sin \theta_s - \sin \theta_r)\right]} \ . \tag{4}$$

This expression fully describes the antenna's response to the signal p(t) received from the θ_s direction when the r-f delay lines are set to steer the main beam in the direction θ_r. The summation term describes the envelope shape of the array's output. If p(t) is a pulse whose length is comparable with the aperture transit time, then the
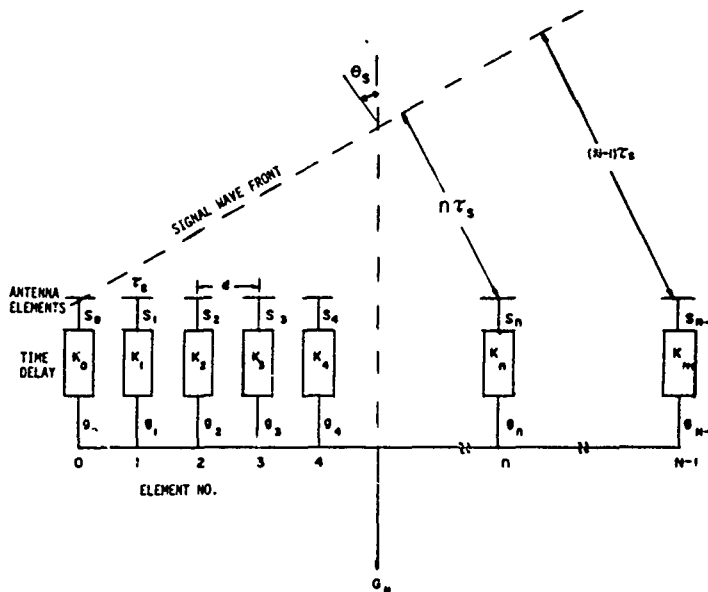
Figure 1. R-F Time Delay Steered Array Antenna

output for $\theta_s \neq \theta_r$ will have a ramp-like leading edge and trailing edge [2]. The second term accounts for the output carrier frequency and phase. The last expression is the familiar array factor.

When the main beam is pointed in the direction of the received signal θ_s, i.e., $\theta_r = \theta_s$, equation (4) reduces to

$$G_N = p\left(t - \frac{Nd}{c} \sin \theta_s\right) e^{j\omega_s \left(t - \frac{Nd}{c} \sin \theta_s\right)}. \tag{5}$$

The output signal is seen to be undistorted and identical to the input signal except for a shift in time due to the array delay.

III. I-F TIME DELAY STEERING

Figure 2 is the block diagram of an N-element wideband, equally spaced, linear array receiving system* in which the r-f time delay device has been replaced by a similar variable delay at i-f. Each channel or element in the array contains a wideband low noise r-f amplifier to establish the system noise figure and overcome mixer losses. The preamplifier is followed by a wideband mixer (parametric converters have also been used in place of both r-f amplifier and mixer [5]) and variable delay line K_n with impulse response given by equation (1). Here, however, the delay τ_n is defined as

$$\tau_n = (N-n) \tau_T = (N-n) \frac{d}{c} \sin \theta_T . \tag{6}$$
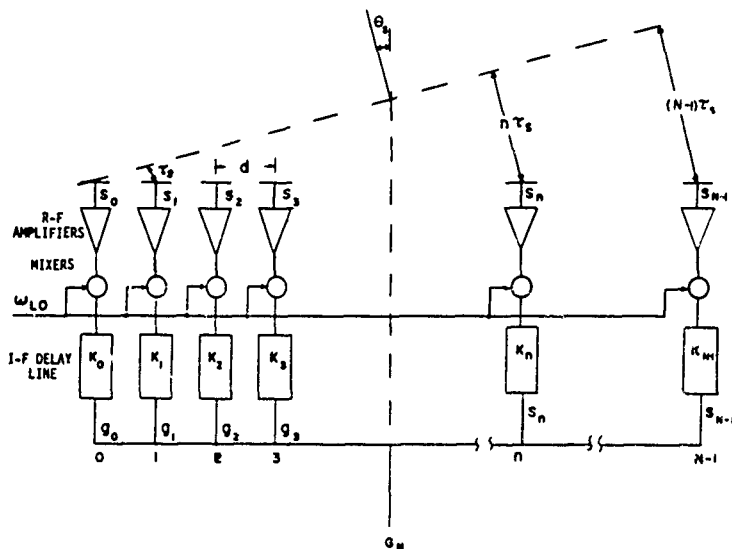
Figure 2. I-F Time Delay Steered Array Antenna
Without Phase Correction

If the delay networks, K_n, are set to the delays τ_n, a signal must arrive from the direction θ_T in order to have element-to-element envelope coincidents at the summing network's input. This direction, θ_T, will be called the "time coincident direction".

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*Although the array is analyzed in terms of the receive case, the method used and conclusions reached apply equally to the transmit case.

In the case of r-f delay steering this is just the direction of the main beam θ_r. For i-f delay steering it will be shown that $\theta_T \not= \theta_r$, i.e., the main beam is not in the same direction as θ_T unless an addition steering system is added.

The outputs of the N delay lines are summed in a wideband beam summing network (the electrical length from each input to the output are assumed equal) to give an output G_N.

A. Effect of Time Delay Steering at I-F With No Phase Correction

First consider what happens when no local oscillator phase shift is inserted. Take the end element, $n = 0$, of the array as reference. A signal $S(t)$ given by Equation (3) impinging on the array from the direction θ_S reaches the nth element $n\tau_S$ seconds after it reaches the reference, where τ_S is the element-to-element propagation delay.

$$\tau_S = \frac{d}{c} \sin \theta_S . \tag{7}$$

The signal induced on the nth element is given by

$$S_n(t) = p(t - n\tau_S) \, e^{j\omega_S (t - n\tau_S)} . \tag{8}$$

The output of the nth mixer $S_n'(t)$ is written

$$S_n'(t) = p(t - n\tau_S) \, e^{j(\omega_{if}t - \omega_S n\tau_S)} . \tag{9}$$

Here the sum frequency has been filtered out. Note that the phase shift that resulted at the signal frequency due to the propagation delay from the 0th to n^{th} element has been preserved.

The i-f delay line output $g_n(t)$ becomes

$$g_n(t) = S_n'(t) * \delta(t - \tau_n)$$

$$= p(t - n\tau_S - \tau_n) \, e^{j[\omega_{if}t - (\omega_{if}\tau_n + \omega_S n\tau_S)]} \tag{10}$$

where * denotes the convolution between the two time functions.

The delay line affects only the terms associated with ω_{if} and not those of ω_S.

If the delay, τ_n, is set to produce element-to-element coincidence of the signal envelope, $p(t)$, (not necessarily phase coherence) for a signal from the direction θ_S, i.e., $\theta_T = \theta_S$, the normalized signal at the output of the summing network can be written

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$$G_N = \frac{1}{N} \left\{ p(t - N\tau_s)\, e^{j[\omega_{if}(t - N\tau_s)]} \right.$$

$$+ p(t - N\tau_s)\, e^{j[\omega_{if}(t - N\tau_s - \omega_{LO}\tau_s)]}$$

$$+ \text{-------}$$

$$+ p(t - N\tau_s)\, e^{j[\omega_{if}(t - N\tau_s - \omega_{LO}n\tau_s)]}$$ (11)

$$+ \text{-------}$$

$$\left. + p(t - N\tau_s)e^{j[\omega_{if}(t - N\tau_s - \omega_{LO}(N-1)\tau_s)]} \right\} .$$

Comparing terms, it can be seen that although the signal envelopes are time coincident (i.e., the leading edge of each element reaches the summing network's output at $t = N\tau_s$ for N elements) a phase gradient of $\omega_{LO}n\tau_s$ has been introduced across the array. This is a direct consequence of the mixer and i-f delay. The presence of this gradient phase steers the direction of the main beam, θ_r, away from the direction of the received signal, θ_s, to a new direction.

Writing the series in closed form and expressing the τ_s in terms of θ_s, the normalized output is

$$G_N = p(t - \frac{Nd}{c} \sin \theta_s)\, e^{j\left[\omega_{if}(t - \frac{Nd}{c} \sin \theta_s) - \omega_{LO}\frac{(N-1)d}{2c} \sin \theta_s\right]}$$

$$\frac{\sin\left[\omega_{LO} \frac{Nd}{2c} \sin \theta_s\right]}{N \sin\left[\omega_{LO} \frac{d}{2c} \sin \theta_s\right]} .$$ (12)

Since the main beam is no longer pointed in the signal direction (the time coincident direction, θ_T), the received signal is attenuated. This attenuation is determined by the last terms of Equation (12).

B. Determination of Main Beam Direction

In order to determine the main beam's new direction, θ_r, as a function of the delay coincident direction, θ_T, given by Equation (6), Equation (10) (the expression for the nth element signal with respect to the reference element, $n = o$) must be written in terms of the angles θ_T and θ_s.

$$g_n(t) = p\left[t - \frac{Nd}{c} \sin \theta_T - \frac{nd}{c} (\sin \theta_s - \sin \theta_T)\right]$$

$$e^{j\left[\omega_{if}\left(t - \frac{Nd}{c} \sin \theta_T\right) - \frac{nd}{c} \omega_s \left(\sin \theta_s - \frac{\omega_{if}}{\omega_s} \sin \theta_T\right)\right]} .$$ (13)

Summing the N element signals and normalizing, yields an expression for the summing network's output, G_N.

$$G_N = \frac{1}{N}\left\{\sum_{n=0}^{N-1} p\left[t - \frac{Nd}{c}\sin\theta_T - \frac{nd}{c}(\sin\theta_s - \sin\theta_T)\right]\right\}$$

$$e^{j\left[\omega_{if}\left(t - \frac{Nd}{c}\sin\theta_T\right) - \omega_s\frac{(N-1)d}{2c}\left(\sin\theta_s - \frac{\omega_{if}}{\omega_s}\sin\theta_T\right)\right]}$$

$$\frac{\sin\left[\omega_s\frac{Nd}{2c}\left(\sin\theta_s - \frac{\omega_{if}}{\omega_s}\sin\theta_T\right)\right]}{N\sin\left[\omega_s\frac{d}{2c}\left(\sin\theta_s - \frac{\omega_{if}}{\omega_s}\sin\theta_T\right)\right]} \cdot \qquad (14)$$

To determine the array's main beam direction or position, i.e., $\theta_s = \theta_r$, (signal direction where phase addition or maximum G_N occurs) the argument of the denominator of the array filter function must be set equal to zero. That is,

$$\omega_s\frac{d}{2c}\left(\sin\theta_r - \frac{\omega_{if}}{\omega_s}\sin\theta_T\right) = 0. \qquad (15)$$

Solving for the main beam position θ_r (i.e., the value of θ_s for which the filter factor is maximum),

$$\theta_r = \sin^{-1}\left[\frac{\omega_s - \omega_{LO}}{\omega_s}\sin\theta_T\right] \text{ radians.} \qquad (16)$$

It is seen that the position of the main beam (direction of coherent summation) is dependent on both the delay coincident direction, θ_T, i.e., setting of the delay lines, and the carrier frequency, ω_s. Note that as the carrier frequency varies, both ω_s and ω_{if} vary by the same number of cycles per second, however, the percent variation of each is different.

The variation of θ_r with frequency is given by

$$\frac{d\theta_r}{d\omega_s} = \frac{1}{\omega_s}\sqrt{1 - \left(\frac{\omega_s - \omega_{LO}}{\omega_s}\sin\theta_T\right)^2}\left[\frac{\omega_{LO}}{\omega_s}\sin\theta_T\right]. \qquad (17)$$

Here $d\omega_s$ is the signal bandwidth. For $\theta_T < 45°$, Equation (17) reduces to

$$d\theta_r \doteq \frac{d\omega_s}{\omega_s}\sin\theta_T \text{ radians.} \qquad (18)$$

The beam movement, in radians, with frequency is seen to be approximately equal to the percent bandwidth times the sin, θ_T.

As an example let us assume that:

$$\omega_3 = 2\pi 5 \text{ GHz}$$

$$\omega_{if} = 2\pi \ 0.5 \text{ GHz}$$

$$\omega_{LO} = 2\pi \ 4.5 \text{ GHz}.$$

Let us assume the direction of delay coincident angle $\theta_T = 20^O$. From Equation (16) the main beam will be phase steered to $\theta_r = 2$ degrees off broadside. In other words, if the array time delay units were set to produce element signal coincidence at the summing network for a signal arriving at an angle of 20 degrees off boresight, the main beam of the antenna in this example would point in a direction 2 degrees off boresight.

If the signal is swept over a 5 percent bandwidth (linear FM for example), the beam will move as described by Equation (18) by

$$d\theta_r = 0.17 \text{ radians} = 9.8 \text{ degrees}.$$

In effect, the beam will appear to have been broadened by 9.8 degrees with a resultant loss in antenna gain in that particular direction.

C. Time Delay Steering With Phase Correction

In order to cause the main beam direction, θ_r, and the time coincident direction, θ_T, to coincide and be independent of frequency, the phase gradient term of Equation (11) must be eliminated before the element signals are summed. This phase gradient can be eliminated by introducing a progressive phase shift ϕ_n, as shown in Figure 3, having a value of

$$\phi_n = \omega_{LO} n \tau_T = \omega_{LO} \frac{nd}{c} \sin \theta_T. \tag{19}$$

If this shift is accomplished by adjusting the phase of the local oscillator, the main beam of the antenna will now be steered back to the direction, θ_T, as determined by the delay τ_n, i.e., $\theta_T = \theta_r$, and the beam's new position will be independent of frequency. This can be seen as follows. Introducing the local oscillator phase term, the normalized output for the i-f delay and phase steered array now becomes

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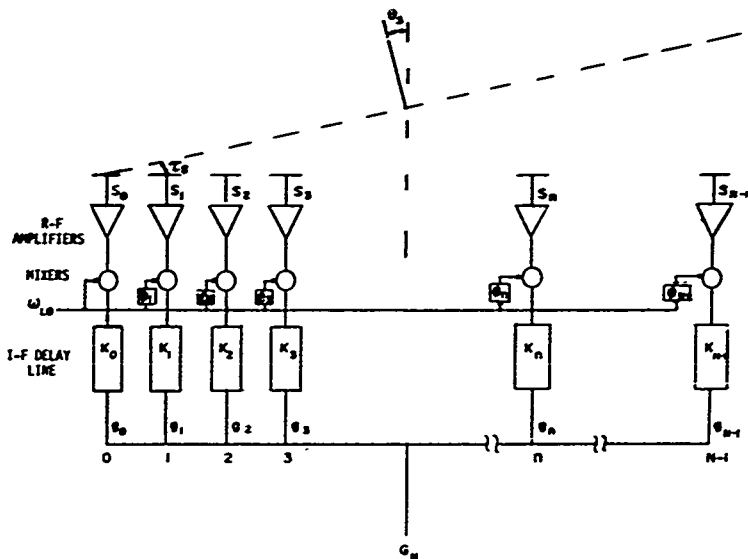
Figure 3. I-F Time Delay Steered Array Antenna
With Phase Correction

$$G_N = \left\{ \frac{1}{N} \sum_{n=0}^{N-1} p\left[t - \frac{Nd}{c} \sin \theta_r - \frac{nd}{c} (\sin \theta_s - \sin \theta_r) \right] \right\}$$

$$e^{j\left[\omega_{if}\left(t - \frac{Nd}{c} \sin \theta_r\right) - \omega_s \frac{(N-1)d}{2c} (\sin \theta_s - \sin \theta_r) \right]} \quad (20)$$

$$\frac{\sin\left[\omega_s \frac{Nd}{2c} (\sin \theta_s - \sin \theta_r) \right]}{N \sin\left[\omega_s \frac{d}{2c} (\sin \theta_s - \sin \theta_r) \right]} \cdot$$

When the main beam is pointed in the direction of the received signal, $\theta_s = \theta_r$, the output expression reduces to

$$G_N = p\left(t - \frac{Nd}{c} \sin \theta_s \right) e^{j\omega_{if}\left(t - \frac{Nd}{c} \sin \theta_s\right)} \quad \vdots$$

$$(21)$$

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Comparing Equation (21) with Equation (12), where no local oscillator phase shift was introduced, it can be seen that the addition of the phase shift has eliminated the antenna loss term and made the beam direction independent of frequency. This expression indicates that the i-f delay-phase steered array has the same response as the r-f delay steered case given by Equation (5). The only difference in the two expressions is the output frequency.

It is interesting to note that if the local oscillator signal of each element were radiated by its respective antenna element, the transmitted beam would be in the θ_s direction. In effect the delay provides alignment of the envelopes while the local oscillator phase shift provides alignment of the phase.

D. Implementation of Phase Steering

There are any number of ways to obtain the desired local oscillator phase shift. Any method used to steer a narrowband phased array by shifting the local oscillator phase would be applicable here. One such example might be to pass the reference oscillator through a narrowband adjustable delay line, τ_n', to obtain the desired phase shift, ϕ_n. The network must have the delay

$$\tau_n' = \frac{d\phi_n}{d\omega}\bigg|_{LO} = n\tau_s \ . \tag{22}$$

The delay required in the first signal element path (n = o) is the same as the delay required in the local oscillator of the last element mixer (n = N). The delay in the second signal element path (n = 1) is identical to the delay of next-to-last element mixer local oscillator, etc.

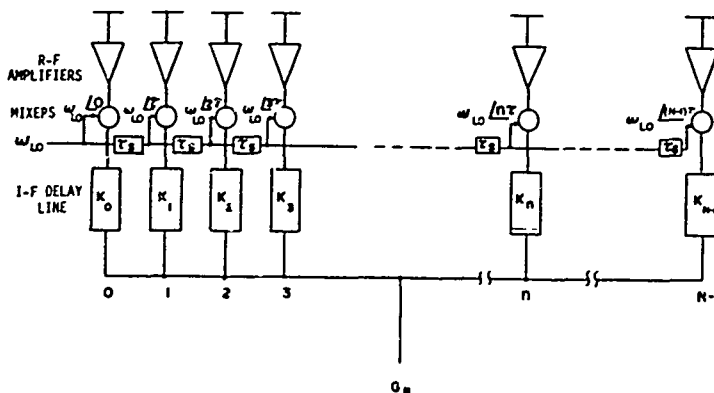A possible implementation using this technique is shown in Figure 4.

Figure 4. Implementation of an I-F Time Delay Steered Array Antenna

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Here, a narrowband delay line having a delay equal to τ_s is introduced between each element local oscillator. The result is the desired phase shift.

IV. PHASE ERRORS

A. R-F Delay Steering

The difference $\Delta\phi_{rf}$ in phase between the reference and the nth element is obtained from Figure 1 as

$$\Delta\phi_{rf} = \underbrace{\omega_s n\tau_s}_{\substack{\text{Signal} \\ n^{th} \text{ element}}} + \underbrace{\omega_s \tau_n \quad - \quad \omega_s \tau_o}_{\substack{\text{r-f delay} \quad \text{r-f delay} \\ \text{reference} \\ \text{element}}} \qquad (23)$$

When τ_n is selected according to Equation (2) so as to cause the main beam to point in the θ_s direction, $\Delta\phi$ reduces to zero as expected. This assumes no phase or delay errors. It can be seen that a degree of phase error in the r-f delay line of the nth element produces a degree error in $\Delta\phi_{r-f}$. This error as a function of the delay line variation can be written as

$$\epsilon_{rf} = d\left[\Delta\phi_{rf}\right] = \omega_s d\tau_n\Big|_{rf}. \qquad (24)$$

For a given phase error, ϵ, between the two elements, the delay error, $d\tau_n$, that can be tolerated is given by

$$\frac{\epsilon_{rf}}{\omega_s} = d\tau_n\Big|_{rf}. \qquad (25)$$

Dividing through both sides by τ_n yields

$$\frac{\epsilon_{rf}}{\omega_s \tau_n\Big|_{rf}} = \frac{d\tau_n}{\tau_n}\Big|_{rf}. \qquad (26)$$

The right-hand side is the percent delay stability required and is seen to be equal to the required percent phase stability. For example, let us take

$$\omega_s = 2\pi \; 5 \; \text{GHz}$$
$$\tau_n = 20 \times 10^{-9} \; \text{sec.} \qquad (27)$$
$$\epsilon_{rf} = \frac{10 \; \text{degrees}}{57.7} \; \text{radians}$$

Then, $d\tau_n/\tau_n = 0.0278$ percent stability.

Using an analog device, this degree of stability would be difficult, if not impossible, for a large number of devices without some type of feedback. Generally, a digital device using coaxial cable or waveguide is used which simplifies the stability problem considerably; however, temperature, vibration, and stress effects become critical.

B. I-F Delay Steering

The difference, $\Delta\phi_{if}$, in phase between the reference and n^{th} element for this case is obtained from Equation (16) by inserting ϕ_n's as

$$\Delta\phi_{if} = \underbrace{\omega_s n\tau_s}_{\substack{\text{Signal}\\\text{Phase}}} + \underbrace{\omega_{if}\tau_n}_{\substack{\text{i-f Delay}\\\text{Phase}}} - \underbrace{\phi_n}_{\substack{\text{LO}\\\text{Phase}}} \quad - \quad \underbrace{\omega_{if}\tau_o}_{\substack{\text{i-f Delay}\\\text{Phase}}} + \underbrace{\phi_o}_{\substack{\text{LO}\\\text{ref.}}} \cdot \qquad (28)$$

$$\underbrace{\qquad\qquad\qquad\qquad}_{\text{Phase of } n^{th} \text{ element}} \qquad \underbrace{\qquad\qquad}_{\substack{\text{Phase of ref.}\\\text{element}}}$$

When τ_n and ϕ_n are selected according to Equations (5) and (19), $\Delta\phi_{if}$ reduces to zero. Again, this assumes no phase errors. The phase error, ϵ, between the two elements due to an error in both τ_n and ϕ_n is given as

$$\epsilon_{if} = d\left[\Delta\phi_{if}\right] = \underbrace{\omega_{if}d\tau_n}_{\substack{\text{i-f Phase}\\\text{error}}} - d\phi_n \cdot \qquad (29)$$

It is important to note that one degree of phase error introduced within the i-f delay line, or the local oscillator, produces a corresponding one degree error, ϵ_{if}, between the two elements. Therefore, the i-f delay and local oscillator taken together must have the same phase stability as though the delay were performed at r-f. For convenience, let us divide the allowable phase error, ϵ_{if}, evenly between the two steering systems. That is,

$$\frac{\epsilon_{if}}{2} = \omega_{if}d\tau_n \text{ and } \frac{\epsilon_{if}}{2} = d\phi_n \cdot \qquad (30)$$

The local oscillator phase shift, ϕ_n, does not have to be obtained from a delay line as suggested earlier. Since this signal is a CW signal, the redundant 2π radian shifts can be eliminated by using strictly a 2π modulus shifter in the line. With a total phase variation of 360 degrees, the percent phase error that the local oscillator phasing system can tolerate becomes

$$\frac{\epsilon_{if}}{720} = \frac{d\phi_n}{360} \cdot \qquad (31)$$

From our previous example, where $\epsilon_{rf} = 10$ degrees ($\epsilon_{rf} = \epsilon_{if}$), the phasing stability would have to be

$$\frac{d\phi_n}{360} = 1.38 \text{ percent.} \qquad (32)$$

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Turning to the stability required of the i-f delay line, the percent stability can be written from Equation (29) as

$$\frac{\epsilon_{if}}{2\omega_{if}\tau_n\big|_{if}} = \frac{d\tau_n\big|_{if}}{\tau_n\big|_{if}} \quad . \tag{33}$$

Comparing the i-f delay stability with that of the r-f delay stability of Equation (26) yields

$$d\tau_n\big|_{if} = \frac{\omega_s}{2\omega_{if}} \ d\tau_n\big|_{if} \tag{34}$$

In other words, for the same phase stability (the factor 2 appears from assumption of Equation (30), the required delay stability of the i-f delay line is reduced from that of the r-f delay line by one-half the ratio of the r-f to i-f frequencies. Both systems require the same total delay, τ_n. The percent i-f delay line stability can be written as

$$\frac{d\tau_n\big|_{if}}{\tau_n} = \frac{\omega_s}{\omega_{if}} \ \frac{d\tau_n\big|_{rf}}{\tau_n} \quad . \tag{35}$$

Using the numbers in the above example and on i-f frequency of 250 MHz,

$$\frac{d\tau_n}{\tau_n}\big|_{if} = 0.278$$

percent stability, an order of magnitude decrease in the delay stability over that for the r-f case as indicated by Equation (27).

The significant point here is that although a degree of phase shift or error at i-f results in only a degree error at r-f, it takes a much larger delay error at i-f to produce the one degree than it takes at r-f. As an example, a one-nanosecond error in delay at 100 MHz produces a 36-degree phase error. At 1 GHz this delay error would result in a 360-degree phase error.

Comparing the stabilities required of the two steering systems, i.e., the i-f technique, Equations (31) and (32) with that of the r-f technique, Equation (26), the i-f approach does not require as stable a control as the r-f case. However, this stability requirement is offset by the fact that i-f steering requires two separate steering systems, one phase and the other delay.

Since the transmit process is the reciprocal of the receive case, the above analysis holds for both. A given i-f delay error of $d\tau_n\big|_{if}$ corresponding to, say, one degree will produce only one degree error at r-f. The differential delay, $d\tau_n$, between the radiated waveforms of the two elements will still be present but the phase error will correspond to that at the i-f and not at r-f.

As the differential delay between the two element signals increases (assuming no phase error) the processed signal-to-noise ratio will be degraded. It is shown elsewhere [3] that if the differential delay between the two end elements of an array is equal to the signal's pulse width, then the resultant S/N will be degraded by about 3 db. This condition will be equivalent to numerous 2π radians of phase shift. For a bandwidth of 50 percent or less, and phase errors of 10 degrees or so, this type of delay error will produce negligible degradation (less than 0.1 db).

V. CONCLUSIONS

It has been shown that i-f time delay steering of an array antenna will pass a wideband signal without distortion and provide proper beam steering. It is shown that in addition to adding the delay at i-f, an additional incremental phase shift must be introduced into the local oscillator of each mixer to provide coherent element summation. That is, steering a wideband array antenna by i-f time delay steering involves both the phase steering which is sufficient in itself for a narrowband array and time delay steering which is sufficient in itself for a wideband array when the delay is done at the r-f frequency.

It has further been shown that delay stability requirements are relaxed at the lower i-f frequencies. However, the addition of a phasing steering system further complicates the problem.

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13. ABSTRACT

If time delay steering of a wideband array antenna is introduced at the i-f frequency instead of at the r-f level, all of the element signal phases will be different and the summed pulses will not add in-phase to produce a beam in the desired direction.

It is found that when i-f delay steering is used, an additional incremental phase shift must be introduced into the local oscillator of each mixer to produce in-phase summation. The delay provides alignment of the envelopes while the local oscillator phase shift provides in-phase summation. This condition is found to be independent of frequency and thus bandwidth. The effect of i-f delay error on the system's response is discussed.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Array Antennas						
Scanning						
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